Measuring Vision With Temporally Modulated Stripes in Infants and Children with ROP

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Purpose. To determine differences in preferential looking (PL) acuities using stationary and temporally modulated stripe patterns in patients with various stages of retinopathy of prematurity (ROP).

Methods. We measured the PL acuities of 134 patients (ages 4 mo to 13 yr) with various stages of ROP. Patients were divided into six subgroups according to PL vision measured with stationary stripes: (1) equal to or better than 20/200 (n = 24); (2) worse than 20/200 to 20/400 (n = 10); (3) worse than 20/400 to 20/800 (n = 15); (4) worse than 20/800 to 20/1600 (n = 13); (5) worse than 20/1600 to 20/6400 (n = 26); and (6) worse than 20/6400 (n = 46; no stationary vision).

Results. In the group with PL acuity equal to or better than 20/200, no difference in vision was apparent between the two methods. In patients with acuities worse than 20/200 to 20/400, the temporally modulated PL acuities were 0.23 octave better than the PL acuities measured with the stationary stripes. The difference increased to 0.86 and 1.12 octaves in the groups with visual acuities worse than 20/400 to 20/800 and worse than 20/800 to 20/1600, respectively. The difference in the group with PL acuities worse than 20/1600 to 20/6400 was 1.69 octaves. The 46 patients with no stationary vision detected only the temporally modulated stripes.

Conclusions. The results suggest that the PL acuity difference between the temporally modulated and stationary stripes increases with visual impairment. Measuring PL acuity with temporally modulated stripes is an important addition to the evaluation of severely visually impaired subjects. Invest Ophthalmol Vis Sci. 1993;34:496–502.

The preferential looking (PL) test has been useful in clinical settings to evaluate vision in infants and young children. However, some patients with severe visual impairment cannot discriminate the lowest spatial frequency stripes in many PL apparatuses. A number of solutions to this problem have been developed—eg, the low vision card in the set of Teller Acuity Cards (TAC; Vistech Consultants Inc, Dayton, OH), the Visual Function Battery developed by Droste et al,[1] the Modified Visual Function Battery developed by Trese et al,[2] and the Visual Hand Display developed by Kronheim et al.[3]

In a study of severely visually impaired infants and young children, we found that they can detect moving stimuli.[4] We frequently observed patients with severe retinopathy of prematurity (ROP) who could detect moving but not stationary objects.[5] These youngsters could walk around the house without bumping into furniture and cross the street by observing oncoming

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traffic. However, almost all PL examinations are performed using only stationary stripes. To analyze more quantitatively the visual abilities of subjects who depend on motion detection, the visual function also should be evaluated with moving patterns that stimulate the motion detectors. For this purpose, we developed a new PL system capable of presenting both stationary and temporally modulated stripes, the latter provided by counterphasing, consisting of two high-resolution television monitors and the control unit that regulates the pattern presentation.

The purpose of this study was to compare the threshold for detection of stationary versus temporally modulated stripes in patients with varying degrees of visual impairment caused by ROP. We limited the study population to patients afflicted with ROP, because it is a leading cause of severe visual dysfunction and blindness in infants and young children in the United States, resulting from recent dramatic improvement in the survival rate of low-birth-weight infants.[6–8] It is estimated that 550 infants go totally blind and another 2000 youngsters become severely visually impaired annually in the United States.[9]

Another reason for limiting the study group to patients with one pathology is that the statistical analysis is more accurate. Correlating data garnered from a study population with multiple pathologies would be much more complex.

Treatment of severe ROP had been considered hopeless.[10] However, certain patients have regained ambulatory vision because of recent advances in vitreoretinal surgery.[11–13] Needless to say, an accurate measurement of visual acuity in these severely visually impaired youngsters is important from diagnostic and therapeutic standpoints.

SUBJECTS AND METHODS

Subjects

A total of 134 patients (55 men, 79 women) with various stages of ROP, who were examined by us during a 2 yr period, served as the study population. Figure 1 shows the age distribution of the ROP patients at the time of the PL examination. Although the patients' ages ranged from 4 mo to 13 yr (median, 25 mo), most patients were 12 to 24 mo old. The gestational ages of the study patients ranged from 23–32 wk (mean, 26.5; standard deviation, 2.3). The birth weights of the study patients ranged from 514 to 2000 grams (mean, 968.5; SD, 338.1).

All patients were divided into six subgroups according to their PL vision measured with stationary stripes: (1) equal to or better than 20/200 (n = 24); (2) worse than 20/200 to 20/400 (n = 10); (3) worse than 20/400 to 20/800 (n = 15); (4) worse than 20/800 to 20/1600 (n = 13); (5) worse than 20/1600 to 20/6400

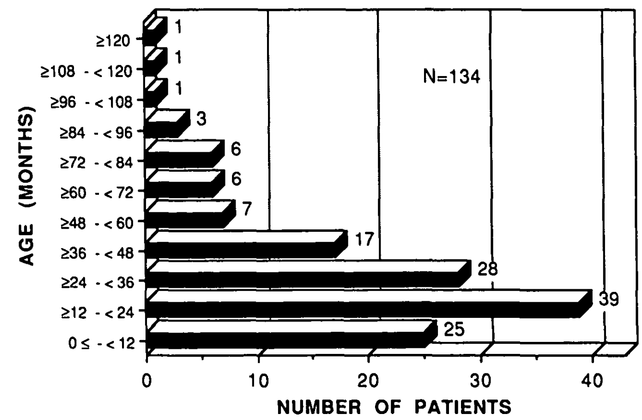

FIGURE 1. The age distribution of 134 ROP study subjects. The abscissa shows the number of patients, and the ordinate denotes the ages at the time of PL acuity measurement.

(n = 26); and (6) worse than 20/6400 (n = 46; no stationary vision). The last group could not detect the largest stationary stripes, but could detect the motion of the stripes when presented with temporal modulation.

The stages of ROP in the study population were as follows: 12 patients had regressed stage 2; 43 had regressed stage 3; and 79 had either stage 4 (n = 6) or stage 5 (n = 73). Three patients with stage 4 and all with stage 5 ROP underwent open-sky vitrectomy (OSV) that resulted in total or partial retinal reattachment.

All phakic patients were carefully refracted, and optical correction was provided with spectacles when indicated. In the 76 patients who underwent OSV, the PL acuity was measured after aphakic correction with spectacles.

Methods

The PL system used in this study consists of two high-resolution television monitors (NEC Multisynch GS 2A, Tokyo, Japan), which present the patterns, and the control unit, which regulates the pattern presentation (Wyse Technology, San Jose, CA). A red light-emitting diode fixation target was placed between the two television monitors to attract the infant's attention during PL testing.

The size of the stimulus display was 25 cm (horizontal) × 19 cm (vertical), which subtended the visual angle of 27.5° × 21.6° from the viewing distance of 48 cm. The mean luminosity was kept at 50 cd/m^2, with attention paid to balancing the level of mean luminosity between the two television monitors. We used square-wave modulated vertical stripes of nine different spatial frequencies (20/6400, 0.094 cycles per degree to 20/25, 24.0 cpd in 1 octave steps from the viewing distance of 48 cm). The PL acuity was measured in the monocular condition at a testing distance of 48 cm. The exact viewing distance was assessed by measuring the distance between the patient and the stimulus display several times during the PL examination. However, when the viewing distance varied because the patient's position changed (which occurred frequently), the PL acuity was adjusted accordingly. In infants younger than 6 mo (their adjusted ages often were 1–2 mo), shorter testing distances (24 or 36 cm) were used frequently. The reversal rate of 2.5 Hz (5 reversals/sec) was used for the temporally modulated stimuli.

The PL acuity was determined monocularly by the up-and-down staircase procedure developed by Wetherill and Levitt[14] and later applied for infant vision use.[15,16] We used the 2-up-and-1-down staircase procedure. When the patient responded correctly to two consecutive stimuli, we proceeded by 1 octave to higher spatial frequency stripes. For each incorrect response within two trials, we returned by 1 octave to a lower spatial frequency. The number of reversals before arriving at threshold ranged up to eight. The threshold was calculated by geometrically averaging the sum of visual acuity values from each of the reversals. Patients 24 mo or older made up a high percentage of the group with good vision and were generally capable of pointing toward the stripes. As a result, the number of reversals was fewer.

The PL acuity was determined with the stationary stripes, then with the temporally modulated stripes. The temporally modulated PL acuity measurement started with the stripes 2 octaves worse than the PL acuity for the stationary stripes, and the same 2-up-and-1-down staircase procedure was repeated. When patients could not detect the lowest frequency stationary stripes, the PL examination started with the largest (0.094 cpd or 20/6400) temporally modulated stripes. The results presented in this study were derived from monocular measurements, and only one recording was presented from each subject.

This standard, forced-choice technique was used with subjects from birth to 15–18 mo of age; for older patients, we used positive reinforcement after the subjects responded correctly.[17] We did not use food as a positive reinforcer. Rather, the parents praised or encouraged the child.

In this study, two acuity comparisons were performed. The first was a direct correlation between the motion and static acuities for the whole population. In the second analysis, the whole group was subdivided into six groups according to the stationary PL acuity level and analyzed to determine whether a difference existed based on the severity of visual impairment. For the most severely visually impaired group—ie, those 46 patients who could detect only the temporally modulated stripes—the exact comparison between the stationary and temporally modulated PL acuity is unavailable. However, in this study, an acuity level of 0.047 cpd (20/12800), which is 1 octave worse than the lowest spatial frequency of 0.094 cpd (20/6400), was assigned to these patients for statistical comparison. To compare the PL acuities obtained with the stationary and temporally modulated stripes, octaves were used as the unit of measure.

The results were analyzed with the one-way analysis of variance test. All acuity scores were converted into log MAR (minimum angle of resolution) values when calculating mean acuity values, computing correlation coefficients, and conducting analysis of variance. When the overall F test was significant, Scheffe's method of multiple comparison was used to compare the visual acuity between the charts. A P value of <0.05 was considered statistically significant.

The clinical work in this study conformed to the Declaration of Helsinki. Before the PL testing, the examination procedure was explained thoroughly to parents, and informed consent was obtained in all cases.

RESULTS

Figure 2 shows the correlation of PL acuities measured with the stationary stripes and the temporally modulated stripes. The scattergram shows the results

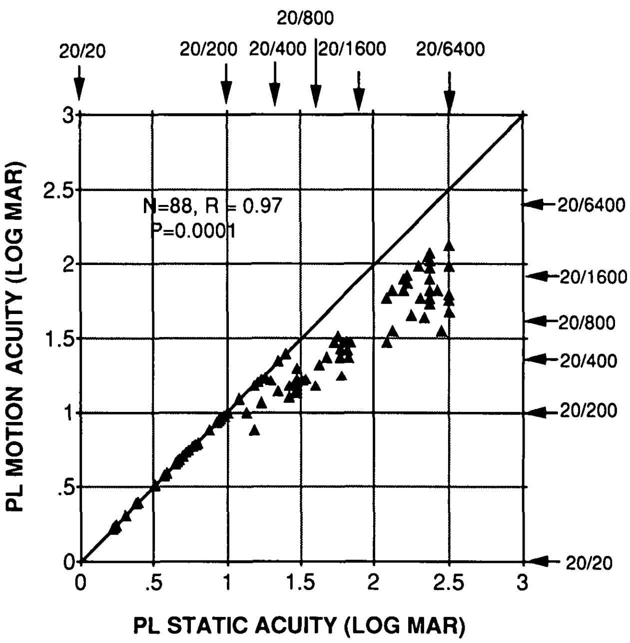

FIGURE 2. The scattergram shows the results of the measurement of PL acuities with the stationary and the temporally modulated stripes in 88 patients. The abscissa shows the PL acuity with the stationary stripes; the ordinate indicates the PL acuity with motion. The points along the oblique line indicate equal static and motion acuities. Both the ordinate and abscissa indicate the visual acuity levels expressed in log MAR and Snellen (expressed as a fraction of 20).

of the 88 patients who detected the stationary stripes. The remaining 46 patients were not included in the data analysis. The overall correlation coefficient was high (r = 0.97), but the correlation pattern seemed to differ depending on the levels of visual acuity. When the level of visual impairment was relatively moderate, the PL acuities were relatively similar; when the level of visual impairment was more severe, the PL acuities measured with the temporally modulated stripes provided a more accurate measure of acuity than those recorded with the stationary stripes.

Figure 3 shows the comparison of PL acuities recorded with the stationary and temporally modulated stripes in 134 patients. Those acuities recorded with the temporally modulated stripes were equal to (n = 32) or better than (n = 102; this included 46 patients who could not detect the largest stationary stripes) those measured with the stationary stripes. The mean PL acuities in these 134 patients measured with the stationary and temporally modulated stripes were 20/1820 (log MAR = 1.96) and 20/770 (log MAR = 1.59), respectively. The PL acuities measured with the temporally modulated stripes were significantly better than those measured with the stationary stripes (F = 9.431, $P = 0.001$). As a group, the difference in visual acuities ranged from 0–3.0 octaves (mean, 1.245; SD, 0.890), implying that in ROP patients, the PL acuities measured with the temporally modulated stripes were better than those measured with the stationary stripes by a factor of more than two.

Figure 4 shows the distribution of the PL acuities measured with the temporally modulated stripes compared with the six different visual acuity levels measured with the stationary stripes.

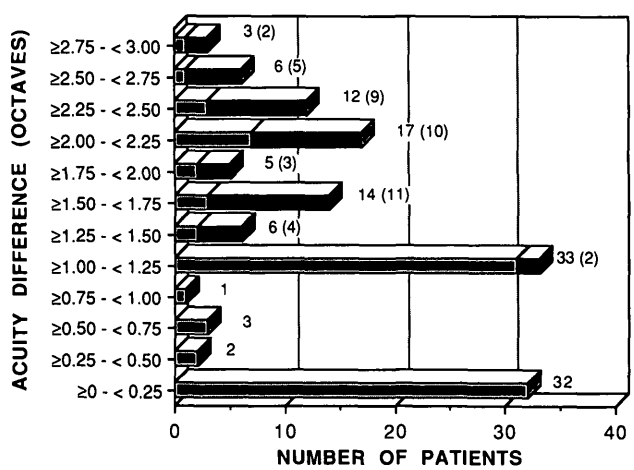

FIGURE 3. The differences between PL acuity measured with the stationary and the temporally modulated stripes in 134 patients. The abscissa shows the number of patients; the ordinate denotes the acuity difference in octaves. The gray and the black portions of each bar indicate, respectively, patients who detected the stationary stripes and those who detected only the moving stripes.

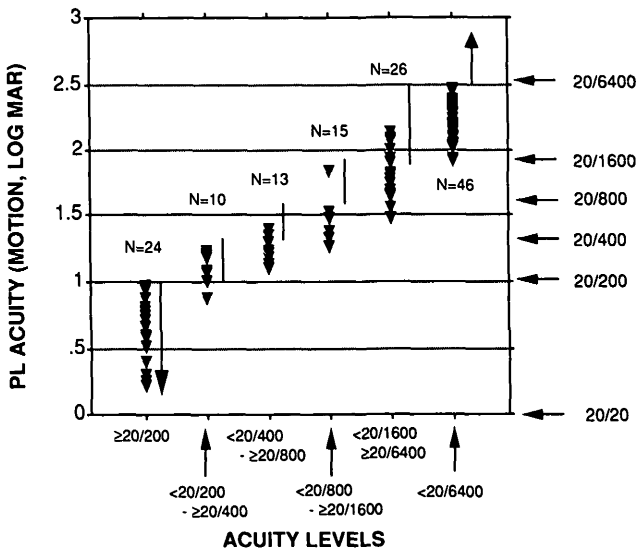

FIGURE 4. The distribution of PL acuity measured with temporally modulated stripes compared with the six levels of PL acuity measured with stationary stripes. The abscissa shows the acuity levels measured with the stationary stripes. The ordinate denotes the PL acuity level expressed in log MAR (left) and Snellen (right). The symbol < indicates worse than; ≥ indicates equal to or better than.

sured with the stationary stripes. The vertical lines beside the acuity results indicate the range of acuity defined by the stationary method at each acuity level. In the group with PL acuities equal to or better than 20/200 (log MAR = 1.0; measured with the stationary stripes), the mean PL acuity for both stripes was 20/90 (0.65). In the patients whose stationary PL acuities were worse than 20/200 (1.00) to 20/400 (1.30), the mean PL acuities measured with the stationary and the temporally modulated stripes were 20/298 (1.17) and 20/254 (1.10), respectively. There was no significant difference in vision between these two measures (Scheffe's F test = 0.098, $P > 0.05$). In the group with stationary PL acuities worse than 20/400 (1.30) to 20/800 (1.60), the mean PL acuities measured with the stationary and the temporally modulated stripes were 20/589 (1.47) and 20/324 (1.21), respectively. By comparison, the PL acuities measured with the temporally modulated stripes were significantly better (Scheffe's F test = 2.11, $P < 0.05$).

In the group with stationary PL acuities worse than 20/800 (1.60) to 20/1600 (1.90), the mean PL acuities measured with the stationary and the temporally modulated stripes were 20/1271 (1.80) and 20/582 (1.46), respectively. In comparison, the PL acuities measured with the temporally modulated stripes were significantly better (Scheffe's F test = 3.17, $P < 0.05$) than those measured with the stationary stripes. In the patients whose stationary PL acuities were worse than 20/1600 (1.90) to 20/6400 (2.51), the mean PL acuities measured with the stationary and the temporally modulated stripes were 20/4325 (2.33) and 20/1340 (1.83), respectively. The PL acuities measured with the temporally modulated stripes also were significantly better (Scheffe's F test = 14.105, $P < 0.05$) than the PL acuities measured with the stationary stripes. The group of severely visually impaired patients (n = 46) who could not discriminate the 20/6400 stationary stripes on the PL test detected the temporally modulated stripes with a mean acuity of 20/3147 (2.20). The highest PL acuity measured with the temporally modulated stripes in this group was 20/1650 (1.92).

Figure 5 shows the means and standard deviation of the PL acuities measured with the stationary stripes and the temporally modulated stripes at different levels of visual acuities based upon the PL acuities measured with the stationary stripes. In the group with stationary PL acuities equal to or better than 20/200 (1.00), there was no difference in visual acuity between these two methods. In the group with stationary PL acuities worse than 20/200 (1.00) to 20/400 (1.30), the average difference between the two methods was 0.23 (SD = 0.34) octave. In the group with stationary PL acuities worse than 20/400 (1.30) to 20/800 (1.60), the average difference between the two methods was 0.86 (SD = 0.39) octave. In the group with stationary PL acuities worse than 20/800 (1.60) to 20/1600 (1.90), the difference increased to 1.12 (SD = 0.24) octaves. In the group with stationary PL acuities worse than 20/1600 (1.90) to 20/6400 (2.51), the difference between these measurements increased to 1.69 (SD = 0.61) octaves. Although a direct comparison is not possible, in the patients who could detect only the temporally modulated stripes, the acuity difference was the largest, with 2.02 (SD = 0.45) octaves (the static acuity of 20/12800, 2.81, was designated here).

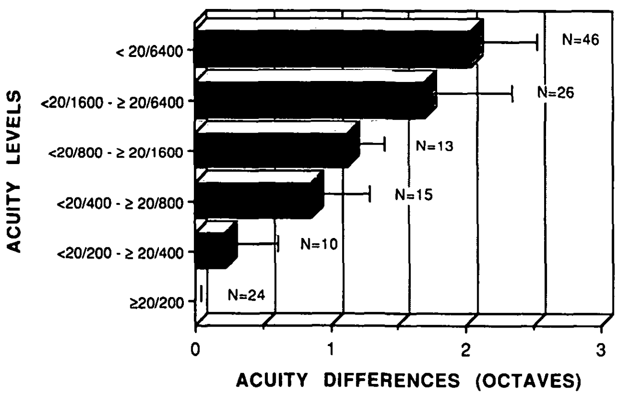

FIGURE 5. The differences between PL acuity measured with stationary and temporally modulated stripes. The abscissa denotes the visual acuity difference in octaves; the ordinate shows the visual acuity levels measured with the stationary stripes. The positive value indicates that the PL acuities with temporally modulated stripes are better than those measured with the stationary stripes. The symbol < indicates worse than; ≥ indicates equal to or better than.

DISCUSSION

In the present study, we found that the correlation between the PL acuities measured with the temporally modulated stripes and the stationary stripes differed depending on the severity of visual impairment. When the level of visual impairment was slight (PL acuity equal to or better than 20/200, log MAR = 1.0), there was no difference between the two modes of stimulation. Several factors (ie, the small number of stripe selections, use of a television monitor as the stimulus display, the small number of reversals) may have accounted for this finding of identical motion and static acuity in subjects with log MAR values of 1 or less. However, as the level of visual impairment increased, the PL acuities measured with the temporally modulated stripes was significantly better than those measured with the stationary stripes. This phenomenon was observed more markedly in cases in which the PL acuity measured with the stationary stripes was 20/400 (1.30) or worse. A significant number of patients with severe ROP (stages 4 and 5; 46 of 134) could detect only the motion of the temporally modulated stripes. When the pattern was presented without temporal modulation, the patients were unable to detect it.

Regarding the comparison of PL acuity measured with the stationary and phase-alternated patterns, Atkinson et al[18] found no difference between the two methods in 1–3-month-old normal infants. Dobson et al,[19] who compared the PL acuities using phase-alternated and stationary checkerboard grating patterns displayed on the cathode ray tube, reported no differences in the PL acuities in normal 2-mo-old infants. Sokol et al[20] measured PL acuity in 2–10-month-old infants and found that visual acuity was not affected by the rate of reversal at 2 mo of age. At age 3 mo and older, the PL acuity measured with the temporally modulated stripes was found to be better than with the stationary stripes. The human visual system is generally believed to have at least two major functions, one being the sustained system, and the other the transient system. When the sustained system (macular function) is intact (as compared with macular impairment)—ie, the central portion of the retina dominates the visual information[21]—it is speculated that the temporal modulation does not affect the visual resolution. In ROP subjects with slight visual impairment, there was no difference in the PL acuities between the two modes of presentation in the present study, a finding similar to the results reported by Atkinson et al[18] and Dobson et al[19] in normal infants. However, when the level of visual impairment increased, the PL acuity recorded with the temporally modulated stripes was always better than with the stationary stripes. The difference became greater as the visual impairment increased.

Katsumi et al,[4] when comparing the pattern reversal visual evoked response (PVER) and the PL acuities (stationary stripes) in infants and young children mostly afflicted with ROP, found that the PL acuity was better than the PVER acuity in patients with slight visual impairment, but in those severely impaired, the PL acuity was poorer than the PVER acuity. We speculated that in severely impaired subjects, the apparent motion evoked with the pattern reversal checkerboard stimulus might have been effective. Sokol and Bloom[22] reported that the peak of the amplitude-check size function curve of the PVER shifted toward larger check sizes in amblyopic patients. Katsumi et al,[23] using normal adult subjects, found that the PVER was recordable with large check sizes, even with defocusing with convex spherical lenses of +20 to +25 diopters. In that study,[23] all subjects experienced apparent motion as the degree of defocus increased. As already reported by Spekreijse et al,[24] the large check size pattern caused the apparent motion effect.

Motion detection may be the only remaining visual function in severely visually impaired ROP patients (ie, severe impairment of the X system). The ability to recognize a moving object may require minimal vision, but this level is useful, important, and even vital to patients with severe ROP, often enabling them to walk around or ride a bicycle.

When analyzing the infant's ability to perceive motion or quantify the level of vision to a moving target, the important factor or parameter to consider is the speed of motion or speed of alteration, temporal frequency. If the stripes move too quickly or too slowly, the subject may not perceive them. As already reported by Sokol et al[20] and Swanson and Birch,[25] the infant's visual function is temporally tuned or dependent upon the temporal frequency. In the present study, we tentatively used the temporal frequency of 2.5 Hz (5 reversals/sec). Although it was not within the scope of this study, we consider it important to analyze the temporal frequency characteristic in visually impaired infants and young children. Sokol et al[20] found temporal tuning at 3.75 and 7 Hz in infants older than 3 mo. Swanson and Birch[25] analyzed the temporal frequency characteristics of young infants and found that 4-mo-old infants were tuned to 2 Hz, and over 8 months they tune to better frequencies. From these results, it may be necessary to use different temporal frequencies at different ages in future investigations. Although only ROP patients were evaluated in this study, it is possible that the temporal frequency characteristic may be affected in certain pathologic conditions, such as optic nerve dysfunction.[26,27] To analyze the optimum temporal frequency, a temporal frequency sweep method[28] may be helpful, because testing PL acuity at various reversal speeds may not be tolerated by these infants.

Another important factor in evaluating PL acuity in visually impaired subjects is the use of a large stimulus field. The stimulus field size used in this study ($27.5° \times 21.6°$) is comparable to the low vision card of the TAC, which we found very effective in the previous study.[5] We generally do not value the ability to detect motion, because it is not considered functional vision. However, if a patient can detect the motion of large, high-contrast objects, he or she can walk about the house without bumping into furniture and cross the street safely, because the patient's movement causes the stationary objects to appear to be moving.

The results of the present study showed that the PL acuity difference between the temporally modulated and the stationary stripes increased as the level of visual impairment increased. Measuring the PL acuity with the stationary stripes and the temporally modulated stripes appears valuable in assessing the level of low vision in severely visually impaired subjects.

Key Words

infant vision, motion detection, preferential looking, retinopathy of prematurity (ROP), stationary vision

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